EXPERIENCE WITH AN INTEGRATED, COMPUTER-CONTROLLED COMMUNICATIONS AND MONITORING SYSTEM AT THE ROBENA MINE

Harry Dobroski
Electrical Engineer
Industrial Hazards and Communications
Pittsburgh Mining and Safety Research Center
Bureau of Mines
U.S. Department of the Interior
Pittsburgh, Pa.

William C. Laubengayer
Engineering Supervisor, Mine Programs
Collins Commercial Telecommunications Division
Rockwell International
Cedar Rapids, Ia.

Robert R. Godard
Chief Engineer/Frick District
U.S. Steel Corporation
Uniontown, Pa.

ABSTRACT

A whole mine, computer-controlled communication and monitoring system for both normal and emergency use is installed and operating in the U.S. Steel Robena Mine complex near Uniontown, Pa. Portions of the system, including the coaxial cable and the key underground and surface phones, have been operating for over a year and a half. During this time the basic concept has been modified and new line amplifiers with directional switches have been developed to eliminate some problems in implementing the loopback feature. The quality of the audio and the availability of the system have been outstanding.

Since early summer almost all subsystems have been completed. The experience with the telephone system itself, the pocket-pager call alert, section wireless radio, hoistphone, television, environmental monitoring, control and monitoring of equipment, voice downlink/code uplink post disaster communications, post disaster through-the-earth monitoring, and the system center failure diagnostic routines are reviewed.

INTRODUCTION

Since the enactment of the Federal Coal Mine Health and Safety Act of 1969, considerable emphasis has been placed on improving underground communications. The Bureau of Mines through both in-house and contract efforts has engaged in a wide variety of programs to solve specific and general communications problems.

Early in 1974, the Bureau ascertained the requirements for an integrated whole mine communications and monitoring (MCM) system suitable for large underground coal mines producing at least two million tons annually. The requirements for such mines and the specifications for the necessary hardware were determined via comprehensive system studies (1).* These studies indicated that the necessary integrated system should consist of a private multi-channel phone system that was simple to install and maintain, highly reliable, offered environmental monitoring, control, extreme flexibility, and could operate under the most severe emergency conditions.

With the necessary requirements and specifications defined, a means of implementation was needed. Since there seemed to be no way of using existing mine communications hardware, a contract was negotiated with Collins Radio Company to adapt an existing system to meet the requirements (2). The system developed uses frequency division multiplex (FDM) techniques and is under computer control. The computer-controlled circuitry assigns frequencies for over 250 channels of communications, control, and monitoring on a coaxial cable. ULF and UHF wireless equipment has been integrated with the system to permit communication with roving personnel and to provide a link to the surface through the earth should the coaxial cable ever be destroyed in a mine disaster.

The system center controls the entire system. It consists of a PDP-11, 16K-word memory computer and associated circuitry, a matrix of indicator lights that displays the status of all underground monitors and controlled equipment, and a teletypewriter (TTY) that provides printed outputs and can be used for inputs, if required.

THE ROBENA MCM SYSTEM - EVALUATION, EXPERIENCES, AND FEATURES

The initial Robena system was designed to operate in the 7-11 MHz region (Channel T7) of the radio spectrum. The coaxial cable chosen for this installation was 7/8 inch diameter for main trunks and .412 inch for branch lines, exhibiting 7 and 15 db/mile loss, respectively. Given this attenuation, it was realized that line amplifiers would be necessary along the cable route to compensate for RF losses.

* Numbers in parentheses indicate References at the end of paper.

Since the system operated only in Channel T7, all line amplifiers were required to be bi-directional, simultaneously amplifying signals in both directions in the course of normal operations. This required the use of hybrid balancing transformers and circuits that required critical adjustments. These amplifers were extremely sensitive to transients and standing waves on the cable. As the system grew, amplifier gain had to be set quite low (5-7 db) to keep them from going into oscillations. If the gain was increased to allow for additional cable, the resulting oscillations would often cause the entire system to become inoperative.

It became obvious that it would be impossible to live with this condition. Any cable break would result in such severe standing waves that oscillations would occur and switching to a redundant loopback cable for continued operation would not be possible. In addition, the low gain settings required the use of far too many amplifiers.

Because of this, the single-channel concept was reexamined and the benefits and drawbacks of one- and two-channel systems were considered in detail. A decision was made to convert to a two-channel system.

The channels selected were T7 (7-11 MHz) and C1 (49-53 MHz). (See Figure 1.) The line amplifers were redesigned so that part of the amplifier handled T7 in one direction, and another part handled C1 in the other direction. A signal going from the system center uses C1, while one from a phone to the system center uses T7. No bi-directional amplification is now required and 30 db of gain is usable with excellent stability. This higher gain has more than compensated for the greater RF cable losses of C1.

In order to modify the system center and telephones for two-channel operation, the hybrid transformers and associated circuits were replaced with frequency translators. Also, because of the amplifier stability, standing waves have little effect, making cable loopback possible.

The loopback is accomplished by installing a redundant cable and a circuit in each amplifier that can cause it to reverse its operating direction. A signal that is always present in normal operation is monitored by each amplifier. The loss of this signal causes each amplifier to reverse its operating direction so that the system remains operative.

Surface and underground telephones form the basis for all communications. All phones are private channel and can be assigned certain features such as call-forwarding, conference calling, etc., by inputs from the TTY. The underground phones can be interfaced with paging transmitters, monitors, control units, or through-the-earth-communication systems. Thirty-six phones are equipped with environmental monitors and display the environmental status at the phones and at the system center.

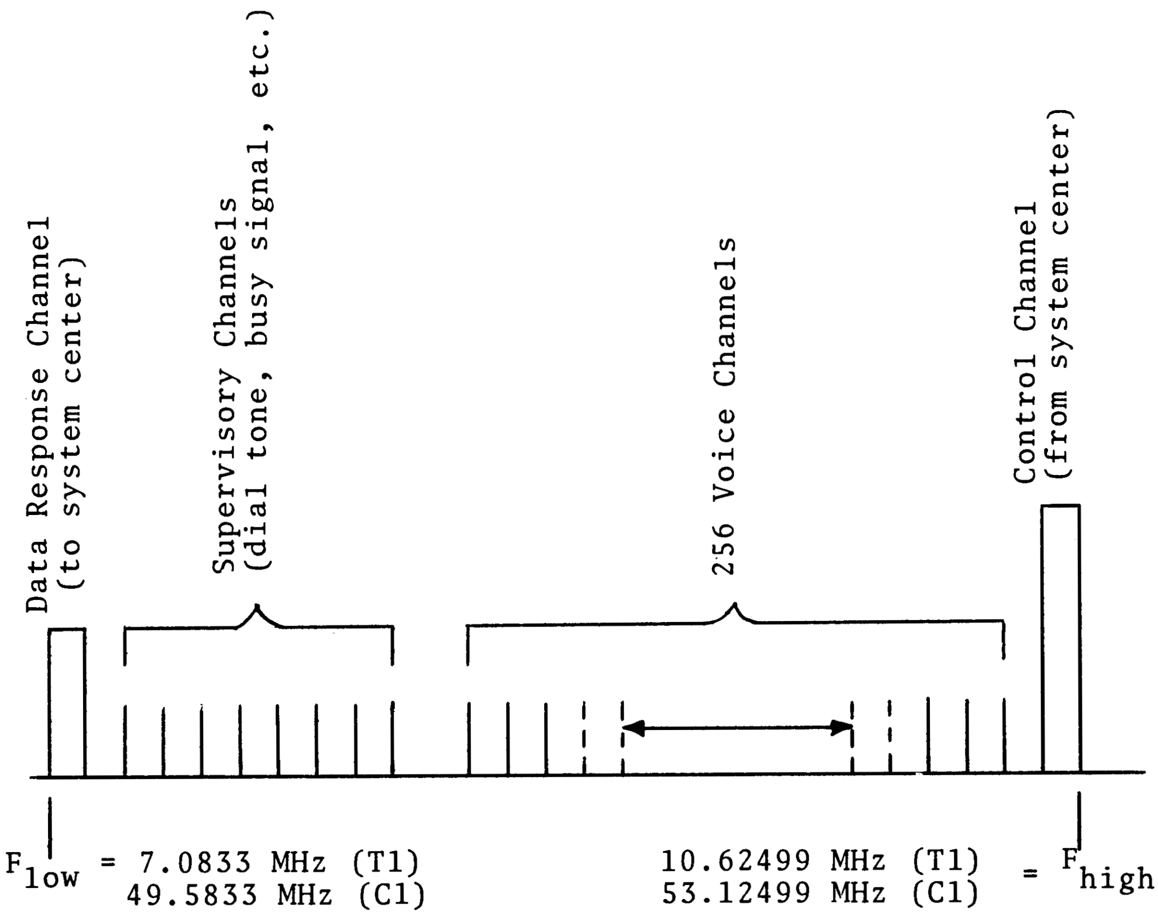

Figure 1--Frequency Spectrum of MCM System

The existing software has been in operation for almost a year, with excellent results. The program is loaded via a paper tape reader on the TTY and requires about a half hour. Consideration was given to purchasing a fast tape reader, but so far it does not seem necessary.

One interesting feature of the Robena system is the recent addition of a radio interface that allows personnel who are equipped with portable radios to access the telephone system without actually using a standard telephone. This interface was designed around a Motorola Inc.* repeater and works in conjunction with standard hand-held UHF transceivers. The interface is designed to dial the dispatcher's phone when it receives a three-tone burst from any transceiver within range. In this way, a roving miner can contact the dispatcher and request that he forward the call for him. Any transceiver can contact any telephone on the system by using the dispatcher as an "operator" and any telephone can contact any transceiver directly by simply dialing the number associated with the interface.

The UHF radios used are Motorola HT and MX series that operated on 465 MHz, 2-watt RF power. Typical range in Robena is 350-450 ft nonline-of-sight, with the MX radios slightly better than the HTs. In addition, the MXs are smaller and more convenient. This range is sufficient to cover a working section. Various antennas such as whips, dipoles, and leaky coaxials are being evaluated on the interface.

Since this interface was designed around a commercial repeater, it still operates as such if the three tone bursts are not transmitted to it. This extends communications between portables to over twice the range available without it.

Although Robena will have only one section equipped with the UHF two-way wireless, there is whole mine paging via ULF wireless. Most underground phones are equipped with an internal ULF transmitter. These transmitters can turn on small pocket pagers selectively so that roving personnel can be contacted anywhere in the mine. Preliminary tests at Robena show that the ULF transmitters can have a maximum range of 4,000 ft, if enhanced by parasitic coupling. A range of about 900 ft is more typical, with no enhancement.

The encoding scheme for the ULF transmitters is via phase shift coding of the ULF carrier controlled by the system center. This scheme theoretically offers the best protection from false triggering

* Use of brand names is for identification purposes only and does not imply endorsement by the Bureau of Mines.

in high noise environments. In practice, a page is initiated by going to any telephone and dialing 7 plus the 3-digit number of a particular pager. Each ULF transmitter will then transmit the required code throughout the mine. If within range, the pager that was called will buzz and light until reset, alerting the wearer that he is being paged.

Of course, there is no way that the person paged knows which telephone originated the page but since the entire process is controlled by the system center, the number of the calling phone is stored in memory. To answer a page, the individual merely goes to the nearest telephone and dials *(star) and his 3-digit page number. The system center then automatically calls the phone that initiated the page and operation is such that the call goes through even if the originating phone is in use.

Since the pagers were delivered to the Bureau for final evaluation in June 1976, insufficient data exist at this writing to report on the operational stability of these devices. Limited testing is being done at the Bureau's Safety Research Mine near Bruceton, Pa. This testing suggests that the pager sensitivity is quite good but certain changes, such as a reduction of physical size and the conversion of the circuit from tuned radio stages to superhetrodyne stages, might be desirable to improve reliability.

Under emergency conditions, the ULF paging transmitter can be manually activated at a given telephone to signal to the surface, through the earth. (See Figure 2.) This would be done only if a man were trapped and could not leave the area and the coaxial cable was destroyed. Each telephone has a protected switch on its front face that, when operated, turns on the ULF transmitter. Surface receivers have been developed that can detect these signals. (3) The Robena system is configured in such a way that if the switch is set under nonemergency conditions, (such as accidental activation of the device or a trapped miner using the ULF transmitter when there was not a cable break) a TTY printout of the event, time of day, and phone location will be printed.

After the surface ascertains a problem and locates the phone that is transmitting through the earth, audio equipment is deployed that enables the surface to talk down to the phone if the phone is equipped with a special voice receiver. Tests at Robena have shown that signals from the phones are readily detectable at the surface. Also, voice messages from the surface are detectable at the phones. The location picked for these tests had about 480 ft of overburden.

Testing of this feature was difficult because of the interference caused by the 360 Hz trolley line power. There was so much noise that the voice from the surface was difficult to comprehend. However, in an emergency situation, this interference would not be present.

Figure 2--An Underground Telephone Being Activated to Signal Through-the-Earth.

Recent tests with newly purchased harmonic notch filters showed that this interference could be eliminated, simulating a true "mine power off" situation. Uplink transmission from the phones is not affected by the trolley line interference.

A new development being evaluated is an underground receiver that turns on modified environmental monitors upon reception of a signal from the surface. The ULF transmitter associated with the phone then transmits the monitor information through the earth, using a simple code. This device was developed for the case of a mine disaster when the cable was broken and it was desired to sample the monitor information without entering the mine. This device will be installed where there is sufficient overburden and a convenient surface site for testing.

In addition to the environmental monitors there are also two equipment monitors, one of which also includes control. In the first case, a fan will be monitored; here, an underground phone is equipped with a special monitor known as a 454L-3. The L-3 will accept three inputs from any NO or NC relays that indicate the status of whatever is being monitored. At this fan location a pressure switch will be monitored which indicates whether or not there is sufficient air flow. If the pressure switch deactivates, the monitor senses it and a signal is immediately sent on the coaxial cable to the system center where an alarm is activated. This particular fan was chosen because it supplies air to a vital area of the mine, is over four road-miles from the system center (approximately 2-1/2 cable miles), and is unmanned. The L-3 appears to work very well. The one disadvantage is the necessity of running a wire pair from the air presure switch on the surface to the L-3 at the underground phone location.

The second case of monitoring and control will be done on water pumps; here, the output pressure of two pumps and the condition of the float switch in the sump will be monitored by another special device known as a 454L-4. In addition, these pumps can actually be controlled from the system center, overriding the automatic controls in the pump room. As in the case of the fan, total status is displayed at the system center.

Since the entire system is under computer control, it has been possible to include a variety of software diagnostics to insure that things are operating properly and that unusual situations within the mine are automatically documented. The printout of environmental condition changes has been mentioned before. A similar TTY printout occurs whenever phones go from line power to battery power and vice versa, or if phones go out of service due to disconnection or failures.

Additional manual diagnostics can be initiated from the system center TTY to evaluate individual phones. In one test, the system center interrogates a phone with digital data 10,000 times in a few minutes. The phone is instructed to respond to these data and a comparision is made of how many times the digital data were returned in error. If an error greater than 1 percent is observed it is an indication that the phone itself may be experiencing electronic problems or the data path between the phone and system center is faulty.

The automatic and manual diagnostics have been extremely useful during the system installation. On several occasions the underground installation crew would improperly install a tap or improperly connect a monitor to a phone. The TTY printout/diagnostic would immediately alert the surface of the problem so that corrective action could be taken. Phones that were suspected of not being up to specifications were checked using the manual diagnostic, thereby saving many hours of installation time.

In one instance at Robena, a false alarm from an existing independent monitoring unit on the Willow Tree fan had caused power to be shut off underground. This caused all underground MCM phones to switch to battery power and this event was duly printed out by the TTY. Mine personnel quickly returned all power (or so they thought) underground. However, the TTY continued to indicate that phones in one area of the mine were still operating on battery power in spite of "all" power being on. A check of that area showed that power was not on, a situation that was easilly detected by the system.

The TTY serves as the system input/output for all tests and changes. In addition to the preceding, it can be used to change phone numbers and phone "privileges." This has been done several times to improve service.

The MCM system uses a portion of the spectrum not used for telephone or monitor operations to provide closed circuit television coverage. A TV camera will be located at the bottom of Colvin Shaft where it can see the entire area. The camera is a standard device, using available 120 vac power and will be connected to the coaxial cable via an interface. A TV monitor will be placed in the hoistroom where it can be seen by the hoist operator. This will allow him to more precisely control the movement of the hoist, when raising or lowering material. This video equipment is totally flexible. The camera and/or monitor can be placed anywhere on the system. At Robena it is thought that the shaft location will be most useful, at least for evaluation purposes. There is also some thought of putting it at the rotary dump.

The hoist at Colvin Shaft has a hoistcage audio communication system installed. There is a transceiver mounted in one of the cages, with a companion transceiver beside the hoistman. These two units do not use the coaxial cable but instead communicate by impressing signals on the hoist cable. There is a coupling device on the headframe and another around the cable above the cage. With this equipment, the hoistman and persons in the cage can speak to one another at any time while the cage is in motion or stopped. A remote handset is attached to the transceiver and placed atop the cage so a man performing a shaft inspection can talk to the hoistman.

INSTALLATION EXPERIENCES

At Robena, it was initially decided to use 7/8-inch cable for the main lines and .412-inch for branch lines. This type of cable was readily available and relatively cheap. The 7/8-inch cable came on 4-foot diameter reels containing 2,500 ft apiece. Forklifts and flatcars were used to get the reels to the desired in-mine sites.

Prior to cable deployment, J-hooks were installed in the mine on existing structures to support the cable. Support was about every 15 ft. The reels themselves were put on flatcars and spooled out via a special reel holder. Installation went rather quickly. In one shift, over 6 miles of 7/8-inch cable was deployed by two six-man crews.

After cable deployment, the wiremen were given a short course in proper splicing techniques. The splicing is done by using a small tubing cutter to remove the jacket of the cable 4 inches from the end; then by cutting away 3/4 inch of outer wall and dielectric all the way down to the center conductor. After cleaning with solvent, the cable is inserted into a special splice and tightened down with two wrenches using moderate torque.

Most of the splices made by the wiremen were good, but after about a year of operation, some problems surfaced. During one system shakedown, when some erratic problems were occurring on the phone system, it was noticed that at some of the splices the cable was indented by tightening the "jacket cutting" tubing cutter too much. In other cases, the splices were not tight enough, or the cable was not inserted far enough into the splice.

This latter problem was also aggravated by the fact that since the J-hooks offered no longitudinal support, tension on the splices was causing them to come loose. The problem was solved by installing strain reliefs at every place where there was a cable cut, such as a splice, tap, or line amplifier.

On the surface, .412-inch cable is used, supported by messenger wire where it goes from building to building, and this technique was considered for underground use also. It is thought, however, that the J-hook/strain relief combination will prove to be best underground. The Bureau has an installation near Morgantown, Pa., where the underground cable is supported by messenger cable and it has proven to be very reliable.

To date, the MCM system uses 11 miles of 7/8-inch cable and 6 miles of .412-inch cable, not counting miscellaneous RG-11 and RG-59 cables that go to various individual phone locations.

One problem, not totally resolved yet, is how to conveniently advance the cable as the sections move forward. At Robena, the cable near advancing sections is configured with a line amplifier at the end of the "permanent" cable. A spool of .412-inch or RG-11 cable, is connected to the amplifier output and run to the telephone. Each time the section advances four breaks beyond the phone, the phone is advanced two breaks. This works well for the RG-11, but the .412-inch cable is more difficult to work with because it is more rigid. The advantage of the .412-inch cable is its low loss. After the spool is completely deployed, the cable is rewound and replaced with 7/8-inch. The process is then repeated.

All the coaxial cable carries both RF and dc. The RF is for systems operation and the dc is to trickle charge the batteries in the underground equipment. Surface phones operate off this dc directly. Four power supplies located on the surface provide the dc for the surface and underground. These power supplies are relay controlled so that they go off if underground power goes off.

Another "wiring" project associated with the system was that of installing the loops that are necessary to transmit the paging signals. Each loop consists of a length of No. 12 wire encircling the coal pillar nearest a telephone that contains a ULF paging transmitter. During the planning of the initial system layout, certain transmitter locations underground were chosen for phones in such a way that the radiated ULF fields would cover as much mine as possible. This would give the desired "whole mine" pager coverage. Some of these sites were not physically investigated prior to installation of cable and phones. As a consequence, there were some locations where it was not possible to get a loop around a coal pillar. In these areas, smaller loops were suspended in the haulageways, resulting in less pager coverage than initially planned. Fortunately, these are not areas of high activity.

The installation of the hoistphones at Robena (Colvin Shaft) was relatively straightforward. At the headframe, a bracket was made to securely hold the coupler around the rope and a cable was run from the coupler to the transceiver located in the hoisthouse. Another coupler was attached to the cable directly above the cage and a cable was run to the transceiver inside. This transceiver was recessed in such a way that no part of it projected. This was necessary because the cage is used not only for men but also material and rail cars loaded with supplies are often taken up and down the shaft. Recessing the transceiver protects it from material that may project from the cars.

The voice quality on the hoistphones is excellent. Even when the volume is set high, there is little distortion. Since these hoistphones were designed to operate up to 10,000 ft, it is not surprising that they operate so well on the 420-ft cable of Colvin Shaft. The personnel who work around the shaft comment that the only time there is any interference is when a rotary dump on the tipple is in operation. The problem is electromagnetic interference (EMI) from the motors and control relays associated with this dump.

OPERATIONAL BENEFITS AND TECHNICAL SUPPORT

The general opinions of the mine personnel who use the system on a day to day basis have been extremely encouraging. The voice channels are clear no matter how far away the communicating phones may be. In some instances, this distance is almost ten miles. There is no hum or static on the line and no degradation due to seasonal effects. Many benefits have been realized by mine management in the ability to contact personnel more rapidly. It is difficult to measure improved productivity or safety, but there is little doubt that improvements do exist. When supervision can quickly and clearly contact underground sections, when a part can be called for without error, when incoming messages can be relayed from phone to phone automatically--these things add up quickly.

It is interesting to note that the operations personnel always use the MCM system when given a choice. They also will not tolerate lengthy shutdowns during system modifications when the system center is sometimes turned off. This is a most meaningful measure of what the system does for daily operations.

No real opinions or data exist at this writing on the monitoring, control, paging or diagnostic aspects of the system. These features have been partially installed on a minewide basis only since June, 1976, and little data exists on reliability or usefulness. There is no reason, however, to believe that they will perform less reliably than the phone system itself.

Since the conversion to a two-channel system early in 1976, there have been no cases where the system has failed requiring the contractor* to dispatch a man to the mine to ascertain the problem. (This does not count early trips required because of an error in the basic two-channel software program.) The program is such that it ignores line transients, power outages, etc. If the program should be erased from memory, it is a simple job to reload.

* Collins Commercial Telecommunications Division, Rockwell International, Cedar Rapids, Ia.

CONCLUSION

The MCM-101 system at Robena is a frequency division multiplex (FDM) system operating under computer control. FDM allows many channels of communication, monitoring, and control on a single coaxial cable. Surface and underground telephones have been developed. The underground telephones are interfaced with various monitors that monitor environmental conditions or the status of equipment. Some phones are interfaced with control devices or wireless paging transmitters. Emergency features are also available.

The basic phone system has been in operation since early 1976 with excellent results. Monitoring, paging, control, etc., have been installed since June 1976. These devices have not yet been thoroughly evaluated.

The system has been well received by mine operations personnel who have made its use part of their daily routine. The general overall opinions are very favorable.

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